

SWIFT IDENTIFICATION OF DARK GAMMA-RAY BURSTS

P. JAKOBSSON,^{1,2} J. HJORTH,¹ J. P. U. FYNBO,¹ D. WATSON,¹ K. PEDERSEN,¹ G. BJÖRNSSON,² AND J. GOROSABEL^{3,4}

Received 2004 September 15; accepted 2004 October 31; published 2004 November 8

ABSTRACT

We present an optical flux versus X-ray flux diagram for all known gamma-ray bursts (GRBs) for which an X-ray afterglow has been detected. We propose an operational definition of dark bursts as those bursts that are optically subluminal with respect to the fireball model, i.e., that have an optical-to-X-ray spectral index $\beta_{\text{ox}} < 0.5$. Out of a sample of 52 GRBs, we identify five dark bursts. The definition and diagram serve as a simple and quick diagnostic tool for identifying dark GRBs based on limited information, particularly useful for early and objective identification of dark GRBs observed with the *Swift* satellite.

Subject headings: dust, extinction — galaxies: high-redshift — gamma rays: bursts

Online material: color figure

1. INTRODUCTION

Dark gamma-ray bursts (GRBs) remain one of the unresolved issues in GRB research. Shortly after the localization of the first GRB afterglows, it became clear that not all GRBs were accompanied by detections of optical afterglows (OAs). In fact, a fairly large fraction, about 60%–70%, of well-localized GRBs did not lead to detections at optical wavelengths (Fynbo et al. 2001b; Lazzati et al. 2002).

Various scenarios have been suggested in order to shed light on dark bursts. The *obscuration scenario* (e.g., Groot et al. 1998; Taylor et al. 1998) ascribes the failed OA detection to extinction. Although there is evidence from X-rays (Galama & Wijers 2001) and damped Ly α absorbers (e.g., Fig. 4 in Vreeswijk et al. 2004) of a high column density of gas around many GRBs, the early high-energy radiation from them and their afterglows can destroy the dust in their environment within a radius up to a few tens of parsecs (Waxman & Draine 2000; Fruchter et al. 2001; Perna et al. 2003). This would pave the way for the afterglow light, but dust in the host galaxy at larger distances could still lead to failure in detecting the OA. In the *high-redshift scenario*, as some fraction of bursts will be located beyond $z \gtrsim 5$ (e.g., Totani 1997; Wijers et al. 1998; Lamb & Reichart 2000), the UV band, which is strongly affected by absorption in the Ly α forest, is redshifted into the optical band. Finally, optical faintness can arise if the OA is intrinsically dark as may happen, e.g., if a relativistic ejecta is decelerated in a *low-density ambient medium* (e.g., Sari et al. 1998; Taylor et al. 2000).

The dark burst fraction places important constraints on the fraction of obscured star formation in the universe (Djorgovski et al. 2001; Ramirez-Ruiz et al. 2002) and the structure of star-forming regions (Lamb 2001; Reichart & Price 2002). Statistical samples studied up to now are unfortunately quite heterogeneous owing to large differences in localization accuracies, localization time since the onset of the burst, and search strategies. Moreover,

effects of observing conditions (e.g., lunar phase) have generally not been taken into account in statistical studies. In many cases, GRBs have been considered dark if no OA was detected, irrespective of how inefficient the search was. In fact, there is no generally accepted criterion for when a GRB is considered dark. With the launch of the *Swift* satellite, it will be essential to have a quick diagnostic tool to flag dark bursts for immediate and/or detailed follow-up (including the near-IR bands) to ensure homogeneity of samples. In this Letter, we present a GRB diagram of the optical flux (F_{opt}) versus the X-ray flux (F_{X}) and propose that those bursts that are optically subluminal with respect to the fireball model, i.e., that have an optical-to-X-ray spectral index $\beta_{\text{ox}} < 0.5$, be defined as dark.

2. CURRENT STATUS

A popular working definition of dark bursts is to set a brightness limit at a given time after the GRB, e.g., $R > 23$ mag at 1–2 days (Djorgovski et al. 2001). Such definitions are necessarily somewhat arbitrary but catch the notion of darkness very well in that the magnitude limits and times correspond to typical search efforts and reaction times. Another approach has been to invoke a physical definition, specifically, to require a dark burst to be a significantly obscured burst. It has been argued that GRB 970828 (Djorgovski et al. 2001) and GRB 000210 (Piro et al. 2002) were most likely dark because of optical obscuration.

Fynbo et al. (2001b) demonstrated that the majority ($\gtrsim 75\%$) of GRBs for which searches for an OA had been unsuccessful were consistent with no detection if they were similar to dim bursts like GRB 000630 in the optical band (see their Fig. 3). Hjorth et al. (2002) found that the dim GRB 980613 had similar properties; i.e., it would have been classified as a dark burst had it not been for the relatively deep search efforts. The afterglow was neither strongly reddened nor at high redshift. This suggests that the classification of the majority of dark bursts was due to searches that simply were not sufficiently sensitive to detect the faint OAs.

Berger et al. (2002) reached a similar conclusion for the dim GRB 020124 and ascribed the faintness to rapid decay, whereas Hjorth et al. (2003) demonstrated that the faintness was largely due to the fairly large redshift of $z = 3.2$ (although not sufficiently large for the burst to be dark owing to Ly α absorption).

¹ Niels Bohr Institute, Astronomical Observatory, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark.

² Science Institute, University of Iceland, Dunhaga 3, 107 Reykjavik, Iceland.

³ Instituto de Astrofísica de Andalucía-CSIC, P.O. Box 03004, E-18080 Granada, Spain.

⁴ Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218.

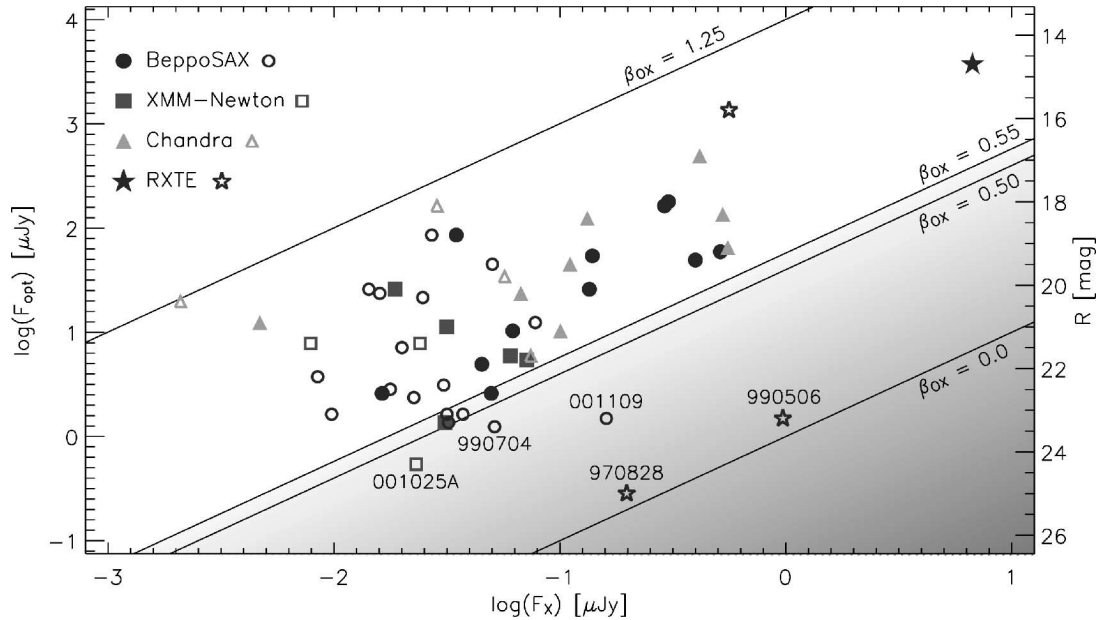


FIG. 1.—Diagram of optical flux vs. X-ray flux for all bursts in Table 1. Optical fluxes, the corresponding R -band magnitudes shown on the right-hand ordinate, and X-ray fluxes have been interpolated/extrapolated to 11 hr. The magnitudes have been corrected for Galactic extinction. Filled symbols indicate optical detections, while open symbols are upper limits. Lines of constant β_{ox} are shown along with the corresponding value. We define dark bursts as those that have $\beta_{\text{ox}} < 0.5$. [See the electronic edition of the *Journal* for a color version of this figure.]

Several studies of the rapidly localized *High Energy Transient Explorer 2* (*HETE-2*) burst GRB 021211 arrived at a similar result: it would have been classified as a dark burst because of its rapid fading but was found to be very bright after 10 minutes. It was not strongly reddened and at a moderate redshift (Fox et al. 2003; Li et al. 2003; Crew et al. 2003; Pandey et al. 2003).

In a study of all *BeppoSAX* bursts with narrow-field instrument follow-up, De Pasquale et al. (2003, hereafter D03) found that most optically faint bursts are also X-ray faint. Some, however, appear even fainter in the optical than expected from X-rays. In a comprehensive study, Rol (2004) concluded that most GRBs can be fitted with standard fireball models. Only three were inconsistent with all models, i.e., fainter than the faintest optical expectation from X-rays. These were classified as dark. In addition, Pedersen et al. (2004) have proposed that GRB 001025A, along with some other bursts, appear optically dark because their (X-ray) afterglow is faint and their synchrotron cooling break, ν_c , is located close to the X-ray band.

Recently, more homogeneous samples have been constructed based on *BeppoSAX* and *HETE-2*. Stratta et al. (2004) find a dark burst fraction of 4/13 for a sample of bright *BeppoSAX* bursts. The better search conditions offered by *HETE-2*, in particular since the soft X-ray camera started to deliver accurate and fast localizations, have resulted in this fraction decreasing further to of the order of 10% (Lamb et al. 2004), as anticipated by Fynbo et al. (2001b).

3. THE OPTICAL FLUX VERSUS THE X-RAY FLUX DIAGRAM

Previous working definitions have been motivated by what makes a burst dark: its faintness. However, in view of the results that a faint burst does not by itself belong to a separate class (notably GRBs 980613, 000630, 020124, and 021211) and the study of D03 that some bursts may be optically faint simply because they are intrinsically faint, it is clear that another parameter must be invoked. D03 used the ratio of optical-to-X-

ray flux. Here we will use the optical-to-X-ray spectral index, which is more directly related to physical properties of afterglows.

In the simplest fireball models, which have been successfully used to interpret the observed properties of GRB afterglows, the spectral index, β ($F_\nu \propto \nu^{-\beta}$), is governed by the energy distribution of electrons, p , and the location of ν_c (e.g., Sari et al. 1998):

$$\beta = \begin{cases} (p-1)/2, & \nu < \nu_c, \\ p/2, & \nu > \nu_c. \end{cases}$$

This result is independent of whether the outflow is collimated or not, or whether the expansion takes place in a constant density or stellar wind environment. In GRB afterglows, the cooling break is frequently found to be located between the optical ($\sim 10^{14}$ Hz) and X-ray ($\sim 10^{18}$ Hz) regimes, giving rise to a break in the spectral distribution somewhere between these two frequencies. In some cases, though, it is positioned either below the optical or above the X-rays.

The value of p is usually found to be larger than 2 ($p < 2$ is not ruled out but requires a high-energy cutoff in the electron energy distribution; see, e.g., Dai & Cheng 2001) and smaller than 2.5. In a study of 36 *BeppoSAX* X-ray afterglows, Piro (2004) inferred an average value of $p = 2.26$. In this simple picture, the average β_{ox} (where the subscript “o” stands for “optical” and “x” for “X-ray”) is expected to lie between 0.5 ($p = 2$, $\nu_c > 10^{18}$ Hz) and 1.25 ($p = 2.5$, $\nu_c < 10^{14}$ Hz).

In a plot of F_{opt} versus F_x , optically subluminal bursts, i.e., bursts fainter than expected from the fireball model, will be situated below the line of constant $\beta_{\text{ox}} = 0.5$. In Figure 1, we plot the $F_{\text{opt}}-F_x$ diagram for all known GRBs that have an X-ray detection and an optical detection or upper limit (as of 2004 August). All data have been interpolated/extrapolated to 11 hr (following D03) and are listed in Table 1. For the upper limits, we have assumed a decay index of $\alpha = 1$ ($F_\nu \propto t^{-\alpha}$) in the

TABLE 1
GAMMA-RAY BURSTS THAT HAVE AN UNAMBIGUOUS DETECTED X-RAY AFTERGLOW AND AN OPTICAL FOLLOW-UP

GRB	Obs.	β_{ox}	R (11 hr)	Ref.	GRB	Obs.	β_{ox}	R (11 hr)	Ref.	GRB	Obs.	β_{ox}	R (11 hr)	Ref.
970111	SAX	<0.83	>22.2		990907	SAX	<0.69	>20.9		020127	CXO	<1.24	>20.4	23
970228	SAX	0.81	19.3	1	991014	SAX	<0.63	>22.4		020322	XMM	0.51	23.3	24
970402	SAX	<0.80	>21.5		991106	SAX	<0.99	>20.2		020405	CXO	0.75	18.3	25
970508	SAX	0.69	21.1	2	991216	CXO	0.96	16.9	10	020427*	CXO	<0.87	>19.8	26
970828	<i>RXTE</i>	<0.05	>25.0		000115	<i>RXTE</i>	<1.06	>15.8	11	020813	CXO	0.65	19.1	27
971214	SAX	0.64	21.9	3	000210	SAX	<0.54	>23.1	12	021004	CXO	0.93	18.4	28
971227	SAX	<0.92	>20.3		000214*	SAX	<0.92	>19.5	13	030226	CXO	0.81	19.5	29
980329	SAX	0.54	22.6	4	000528	SAX	<0.69	>22.5		030227	XMM	0.62	21.7	30
980519	SAX	1.06	18.8	5	000529	SAX	<1.09	>18.8		030328	CXO	0.80	20.2	31
980613	SAX	0.69	22.6	6	000615	SAX	<0.69	>23.1	14	030329	<i>RXTE</i>	0.86	14.7	32
980703	SAX	0.71	20.1	7	000926	SAX	0.87	18.0	15	030528*	CXO	0.63	21.1	33
981226	SAX	<0.51	>23.1		001025A	XMM	<0.43	>24.3	16	030723	CXO	1.07	20.9	34
990123	SAX	0.65	19.4	8	001109*	SAX	<0.30	>23.2	17	031203*	XMM	0.80	21.0	35
990506	<i>RXTE</i>	<0.06	>23.2		010214	SAX	<0.63	>22.7	18	040106	XMM	0.59	21.8	36
990510	SAX	0.86	18.1	9	010220	XMM	<0.94	>21.4	19	040223*	XMM	<0.78	>21.4	37
990627	SAX	<1.02	>20.1		010222	SAX	0.64	19.2	20	040701	CXO	<1.17	>18.1	38
990704	SAX	<0.43	>23.4		011030	CXO	<0.59	>21.7	21					
990806	SAX	<0.51	>23.3		011211	XMM	0.98	20.1	22					

NOTES.—A burst is marked with an asterisk if the follow-up was not carried out in the R band or a deeper limit was available in another band. In these cases, we assumed a spectral index of 0.6 to transform to the R band. If a burst fulfills our dark burst criteria, i.e., has $\beta_{\text{ox}} < 0.5$, its name is written in boldface. A total of five bursts are classified as dark according to our proposed scheme. The references refer to the optical follow-up; if void, they are extrapolated from the R -band magnitudes listed in Fynbo et al. (2001b). The magnitudes have been corrected for Galactic extinction.

REFERENCES.—(1) Galama et al. (2000); (2) Pedersen et al. (1998); (3) Diercks et al. (1998); (4) Reichart et al. (1999); (5) Jaunsen et al. (2001); (6) Hjorth et al. (2002); (7) Holland et al. (2001); (8) Castro-Tirado et al. (1999); (9) Harrison et al. (1999); (10) Halpern et al. (2000); (11) Gorosabel et al. (2000); (12) Piro et al. (2002); (13) Rhoads et al. (2000); (14) Maiorano et al. (2004); (15) Fynbo et al. (2001a); (16) Pedersen et al. (2004); (17) Castro Cerón et al. (2004); (18) Rol et al. (2001); (19) Berger et al. (2001); (20) Stanek et al. (2001); (21) Rhoads et al. (2001); (22) Jakobsson et al. (2003); (23) Lamb et al. (2002); (24) Bloom et al. (2002); (25) Bersier et al. (2003); (26) this work; (27) Urata et al. (2003); (28) Holland et al. (2003); (29) Pandey et al. (2004); (30) Castro-Tirado et al. (2003); (31) Burenin et al. (2003); (32) Lipkin et al. (2004); (33) Rau et al. (2004); (34) Fynbo et al. (2004); (35) Malesani et al. (2004); (36) Masetti et al. (2004); (37) Simoncelli et al. (2004); (38) de Ugarte Postigo et al. (2004).

extrapolation. We note that the significance level of reported upper limits vary between bursts, ranging between 2σ and 5σ .

All R -band magnitudes in Table 1 have been corrected for foreground (Galactic) extinction using the reddening maps of Schlegel et al. (1998). At 11 hr, the OA is usually sufficiently bright that the host galaxy contribution is negligible, but whenever possible we have used the host-subtracted magnitudes reported in the literature. For the *BeppoSAX* bursts, we have taken the 1.6–10.0 keV X-ray flux at 11 hr from D03 and calculated the flux density at 3 keV. The same procedure was carried out for the *Rossini X-Ray Timing Explorer* (*RXTE*) bursts, except the 2–10 keV X-ray flux was obtained from various sources in the literature. For the *XMM-Newton* and *Chandra X-Ray Observatory* (*CXO*) data, the flux density at 3 keV was derived from the best-fit single power law with Galactic absorption to the 2–10 keV data. This energy (3 keV) was chosen as it is relatively insensitive to absorption and requires very little extrapolation of the data since it is close to the center of the bandpass with respect to total counts, thus yielding a reliable flux density. Data from *XMM-Newton* were reduced in a standard way using the *XMM-Newton* Science Analysis System (ver. 6.0.0) and the latest calibration files. The *CXO* data were reduced in a standard way using CIAO (ver. 3.0.2) and the latest calibration files (CALDB, ver. 2.27).

4. DISCUSSION

Bursts that fulfill our criterion $\beta_{\text{ox}} < 0.5$ are classified as dark and are printed in boldface in Table 1. We find five certain dark bursts out of a sample of 52 GRBs, consistent with the trend that the dark burst fraction is approaching a level of about 10% (e.g., Lamb et al. 2004). It is clear from Figure 1 that bursts with no optical counterparts tend to be X-ray faint, as concluded by D03.

As long as a GRB optical and X-ray flux is estimated at the same point in time, the burst can be located in the $F_{\text{opt}}-F_{\text{X}}$ diagram. To the extent that the simple external shock fireball model can be applied,⁵ a burst will either move along constant β_{ox} lines with time (if the optical and X-ray bands are positioned on the same power-law segment) or move along lines with a slightly different slope (if $10^{14} \text{ Hz} < \nu_c < 10^{18} \text{ Hz}$). In the *Swift* era, the data will be obtained within the first hour; hence, information from the early X-ray light curve or spectrum could be used to estimate p , making it possible to set a limit on β_{ox} for individual bursts (making a universal β_{ox} cutoff unnecessary). However, this relies on instant availability of data and is potentially hampered by, e.g., reverse shocks and light-curve fluctuations.

Dark bursts, i.e., bursts located below the line of constant $\beta_{\text{ox}} = 0.5$ in the $F_{\text{opt}}-F_{\text{X}}$ diagram, are guaranteed to be special in the sense that, with respect to the fireball model predictions, they have either a diminished optical flux or an excessive X-ray flux. The former could be due to high redshift or obscuration, while the latter could be caused by X-ray emission lines (e.g., Reeves et al. 2002) or thermal emission. An X-ray-faint burst with a low value of $p < 2$ will also be classified as dark in this scheme. It is important to note that, using this definition of dark bursts, there is no assurance that we will catch *all* obscured or high- z bursts. If, for instance, for a particular burst $p = 2.5$ and $\nu_c < 10^{14} \text{ Hz}$, it will have a high intrinsic β_{ox} value and there is no guarantee that high redshift or optical obscuration will shift β_{ox} below 0.5. Moreover, to answer the question why a specific burst is dark, it must be modeled in detail; the $F_{\text{opt}}-F_{\text{X}}$ diagram is only a quick diagnostic tool.

We may consider bursts with $0.50 \leq \beta_{\text{ox}} \leq 0.55$ as poten-

⁵ Assuming an unchanged OA spectrum and that the effect of the reverse shock does not dominate the optical flux (Piran 1999).

tially dark. We identify five such bursts, namely, GRBs 980329, 981226, 990806, 000210, and 020322. If the value of p is universal (e.g., Waxman 1997), with $p \approx 2.2$, the lower limit on β_{ox} allowed in the fireball model is closer to 0.6. This would shift the aforementioned five bursts into the dark burst category.

The imminent launch of the multiwavelength observatory *Swift*, expected to detect ~ 100 GRBs per year, offers a unique chance to construct a homogeneous sample with well-understood selection criteria. *Swift* will reach an X-ray limit of ~ 8 mcrab at 60 s and an optical limit of $R \sim 22$ mag at ~ 300 s (Gehrels et al. 2004). For a *Swift* burst with an X-ray afterglow detected above this flux limit and no detection in the Ultraviolet and Optical Telescope image, the value of β_{ox} will be below 0.1. This implies that the early (few minutes after the burst) *Swift*

data will be adequate to get a rough location of the burst in Figure 1 and hence to initiate dedicated follow-up observations.

We thank J. Bloom, C. Kouveliotou, D. Lazzati, E. Rol, and R. Wijers for discussions on dark GRBs over the years. We thank the anonymous referee for a critical reading and useful comments on this Letter. P. J. and G. B. gratefully acknowledge support from a special grant from the Icelandic Research Council. K. P. acknowledges support from the Carlsberg foundation and from the Instrument Center for Danish Astrophysics. This work was supported by the Danish Natural Science Research Council. The authors acknowledge benefits from collaboration within the EU FP5 Research Training Network “Gamma-Ray Bursts: An Enigma and a Tool.”

REFERENCES

- Berger, E., et al. 2001, GCN Circ. 958, <http://gcn.gsfc.nasa.gov/gcn/gcn3/958.gcn3>
- . 2002, ApJ, 581, 981
- Bersier, D., et al. 2003, ApJ, 583, L63
- Bloom, J. S., et al. 2002, GCN Circ. 1294, <http://gcn.gsfc.nasa.gov/gcn/gcn3/1294.gcn3>
- Burenin, R., et al. 2003, GCN Circ. 1990, <http://gcn.gsfc.nasa.gov/gcn/gcn3/1990.gcn3>
- Castro Cerón, J. M., et al. 2004, A&A, 424, 833
- Castro-Tirado, A. J., et al. 1999, Science, 283, 2069
- . 2003, A&A, 411, L315
- Crew, G. B., et al. 2003, ApJ, 599, 387
- Dai, Z. G., & Cheng, K. S. 2001, ApJ, 558, L109
- De Pasquale, M., et al. 2003, ApJ, 592, 1018 (D03)
- de Ugarte Postigo, A., et al. 2004, GCN Circ. 2621, <http://gcn.gsfc.nasa.gov/gcn/gcn3/2621.gcn3>
- Diercks, A. H., et al. 1998, ApJ, 503, L105
- Djorgovski, S. G., Frail, D. A., Kulkarni, S. R., Bloom, J. S., Odewahn, S. C., & Diercks, A. H. 2001, ApJ, 562, 654
- Fox, D. W., et al. 2003, ApJ, 586, L5
- Fruchter, A., Krolik, J. H., & Rhoads, J. E. 2001, ApJ, 563, 597
- Fynbo, J. P. U., et al. 2001a, A&A, 373, 796
- . 2001b, A&A, 369, 373
- . 2004, ApJ, 609, 962
- Galama, T., & Wijers, R. A. M. 2001, ApJ, 549, L209
- Galama, T., et al. 2000, ApJ, 536, 185
- Gehrels, N., et al. 2004, ApJ, 611, 1005
- Gorosabel, J., et al. 2000, GCN Circ. 563, <http://gcn.gsfc.nasa.gov/gcn/gcn3/563.gcn3>
- Groot, P. J., et al. 1998, ApJ, 493, L27
- Halpern, J. P., et al. 2000, ApJ, 543, 697
- Harrison, F. A., et al. 1999, ApJ, 523, L121
- Hjorth, J., et al. 2002, ApJ, 576, 113
- . 2003, ApJ, 597, 699
- Holland, S. T., et al. 2001, A&A, 371, 52
- . 2003, AJ, 125, 2291
- Jakobsson, P., et al. 2003, A&A, 408, 941
- Jaunsen, A. O., et al. 2001, ApJ, 546, 127
- Lamb, D. Q. 2001, in Gamma-Ray Bursts in the Afterglow Era, ed. E. Costa, F. Frontera, & J. Hjorth (Berlin: Springer), 297
- Lamb, D. Q., & Reichart, D. E. 2000, ApJ, 536, 1
- Lamb, D. Q., et al. 2002, GCN Circ. 1230, <http://gcn.gsfc.nasa.gov/gcn/gcn3/1230.gcn3>
- . 2004, NewA Rev., 48, 423
- Lazzati, D., Covino, S., & Ghisellini, G. 2002, MNRAS, 330, 583
- Li, W., Filippenko, A., Chornock, R., & Jha, S. 2003, ApJ, 586, L9
- Lipkin, Y. M., et al. 2004, ApJ, 606, 381
- Maiorano, E., et al. 2004, in ASP Conf. Ser. 312, Gamma-Ray Bursts in the Afterglow Era, ed. M. Feroci, F. Frontera, N. Masetti, & L. Piro (San Francisco: ASP), 221
- Malesani, D., et al. 2004, ApJ, 609, L5
- Masetti, N., et al. 2004, GCN Circ. 2515, <http://gcn.gsfc.nasa.gov/gcn/gcn3/2515.gcn3>
- Pandey, S. B., Anupama, G. C., Sagar, R., Bhattacharya, D., Castro-Tirado, A. J., Sahu, D. K., Parihar, P., & Prabhu, T. P. 2003, A&A, 408, L21
- Pandey, S. B., Sagar, R., Anupama, G. C., Bhattacharya, D., Sahu, D. K., Castro-Tirado, A. J., & Bremer, M. 2004, A&A, 417, 919
- Pedersen, H., et al. 1998, ApJ, 496, 311
- Pedersen, K., et al. 2004, ApJ, submitted
- Perna, R., Lazzati, D., & Fiore, F. 2003, ApJ, 585, 775
- Piran, T. 1999, Phys. Rep., 314, 575
- Piro, L. 2004, in ASP Conf. Ser. 312, Gamma-Ray Bursts in the Afterglow Era, ed. M. Feroci, F. Frontera, N. Masetti, & L. Piro (San Francisco: ASP), 149
- Piro, L., et al. 2002, ApJ, 577, 680
- Ramirez-Ruiz, E., Trentham, N., & Blain, A. W. 2002, MNRAS, 329, 465
- Rau, A., et al. 2004, A&A, in press (astro-ph/0408210)
- Reeves, J. N., et al. 2002, Nature, 416, 512
- Reichart, D. E., & Price, P. A. 2002, ApJ, 565, 174
- Reichart, D. E., et al. 1999, ApJ, 517, 692
- Rhoads, J., et al. 2000, GCN Circ. 564, <http://gcn.gsfc.nasa.gov/gcn/gcn3/564.gcn3>
- . 2001, GCN Circ. 1140, <http://gcn.gsfc.nasa.gov/gcn/gcn3/1140.gcn3>
- Rol, E. 2004, Ph.D. thesis, Astronomical Institute, Univ. Amsterdam
- Rol, E., et al. 2001, GCN Circ. 955, <http://gcn.gsfc.nasa.gov/gcn/gcn3/955.gcn3>
- Sari, R., Piran, T., & Narayan, R. 1998, ApJ, 497, L17
- Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
- Simioncelli, A., et al. 2004, GCN Circ. 2549, <http://gcn.gsfc.nasa.gov/gcn/gcn3/2549.gcn3>
- Stanek, K. Z., et al. 2001, ApJ, 563, 592
- Stratta, G., Fiore, F., Antonelli, L. A., Piro, L., & De Pasquale, M. 2004, ApJ, 608, 846
- Taylor, G. B., Bloom, J. S., Frail, D. A., Kulkarni, S. R., Djorgovski, S. G., & Jacoby, B. A. 2000, ApJ, 537, L17
- Taylor, G. B., Frail, D. A., Kulkarni, S. R., Shepherd, D. S., Feroci, M., & Frontera, F. 1998, ApJ, 502, L115
- Totani, T. 1997, ApJ, 486, L71
- Urata, Y., et al. 2003, ApJ, 595, L21
- Vreeswijk, P. M., et al. 2004, A&A, 419, 927
- Waxman, E. 1997, ApJ, 485, L5
- Waxman, E., & Draine, B. T. 2000, ApJ, 537, 796
- Wijers, R. A. M. J., Bloom, J. S., Bagla, J. S., & Natarajan, P. 1998, MNRAS, 294, L13